Role of High-Precision GPS in Flood Hazard and Sea Level Rise Studies

Examples from the Mississippi Delta and Greenland

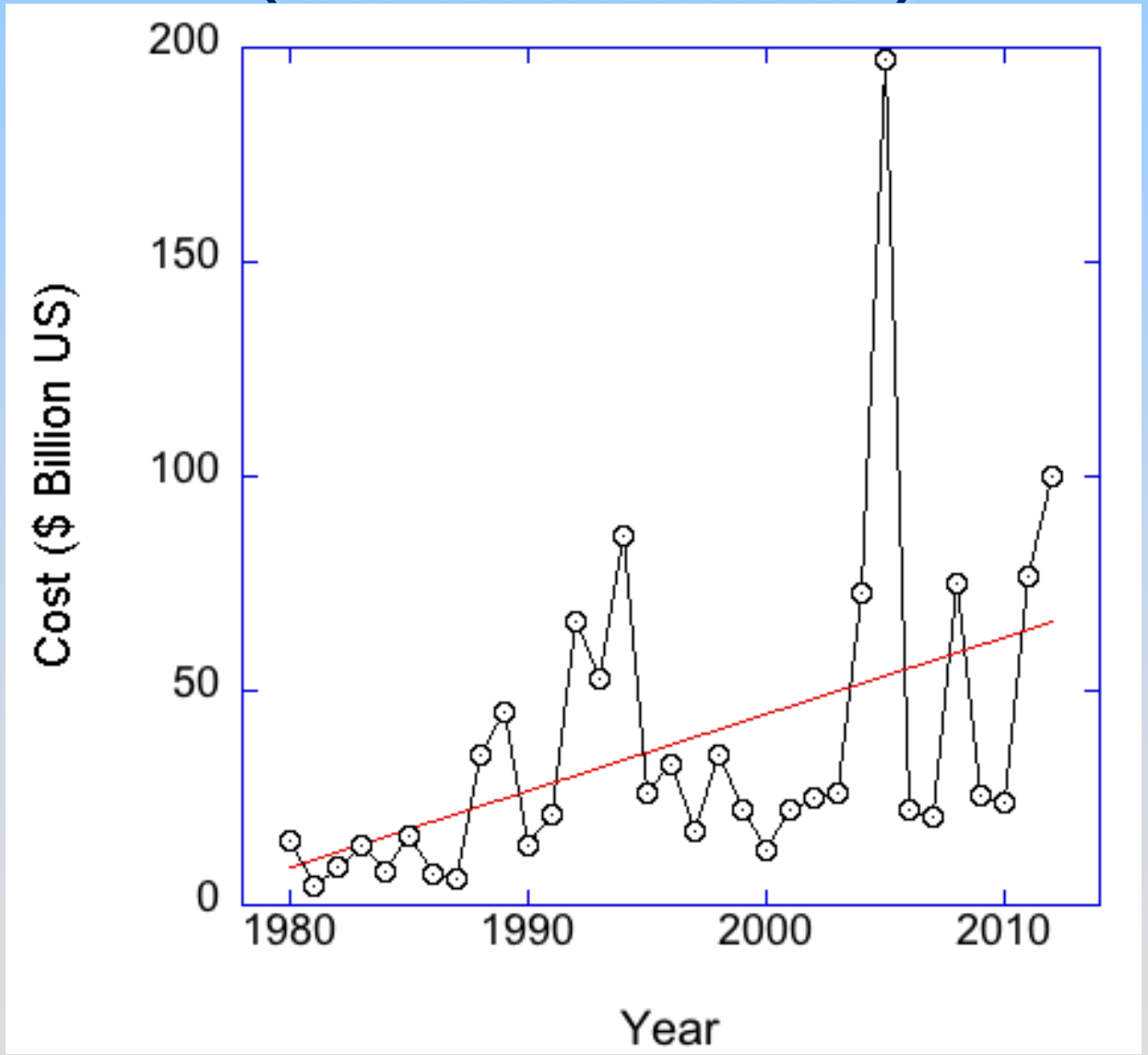
Tim Dixon
University of South Florida

Flood Hazard Background

- Coastal flooding and coastal land loss reflect combined effects of land subsidence and sea level rise (SLR)
- For next few decades, SLR is insignificant (3 mm/yr x 30 yrs = 9 cm) but subsidence effects can be large (20 mm/yr x 30 yrs = 60 cm)
- Example: New Orleans and Mississippi Delta – high land subsidence rates
- On longer time scales, SLR will become significant
- Greenland likely to be significant contributor to SLR over next 100 years

Cost of Hazards

US Domestic, insured + uninsured (most are flood-related)



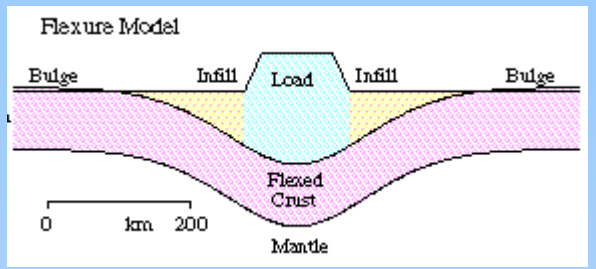
Source:
Munich Re

What causes low elevation and flooding in New Orleans?

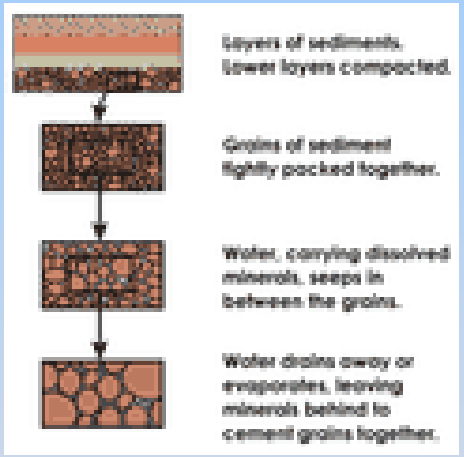
- **Subsidence: combination of effects, exacerbated by anthropogenic intervention in natural system**
- **All deltas subside, but natural sedimentation patterns replenish topmost layer, maintaining height near sea level; Levees restrict natural sedimentation**
- **Would be useful to know quantitative contributions of various subsidence processes**
- **Measuring spatial patterns of subsidence can help distinguish causes**

Causes of subsidence

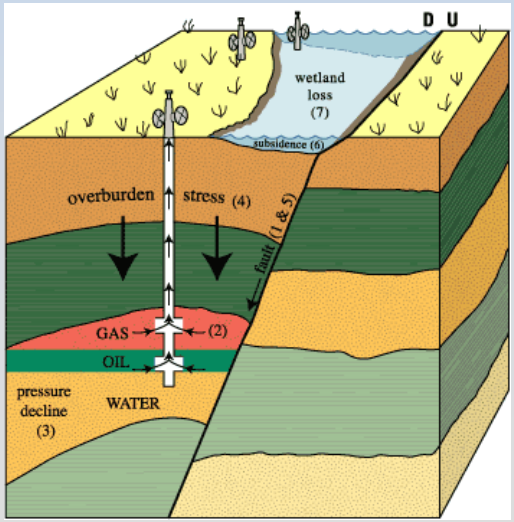
- **Sediment loading**



- **Sediment compaction, dessication, oxidation**



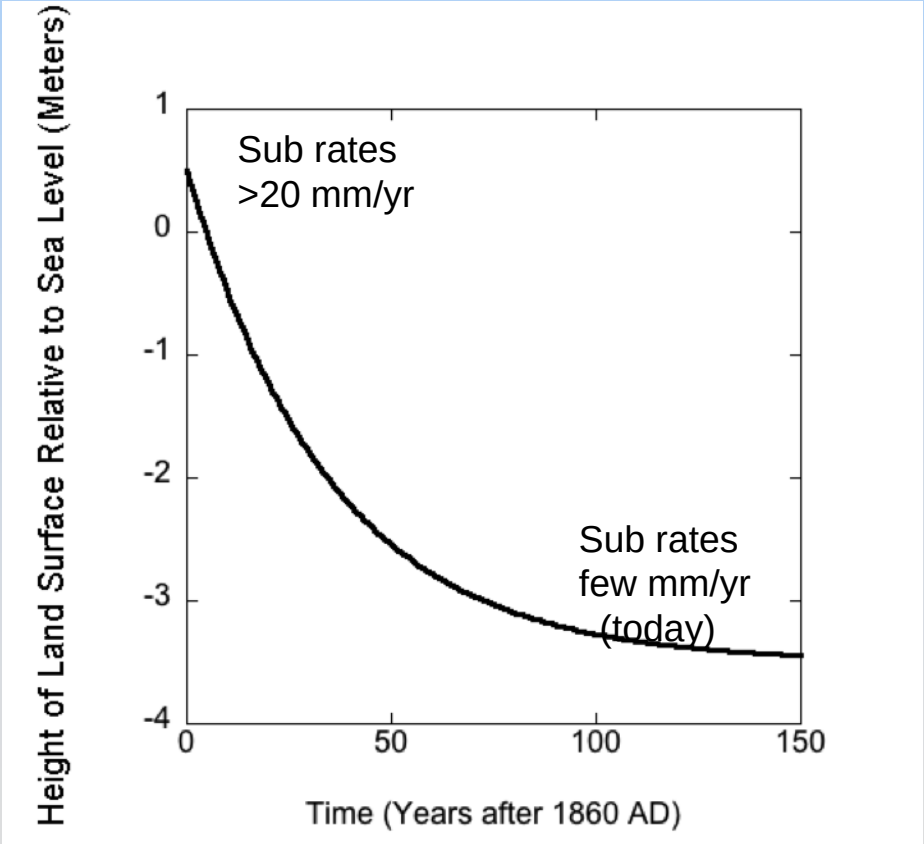
- **Fluid withdrawal: (water; oil and gas production)**



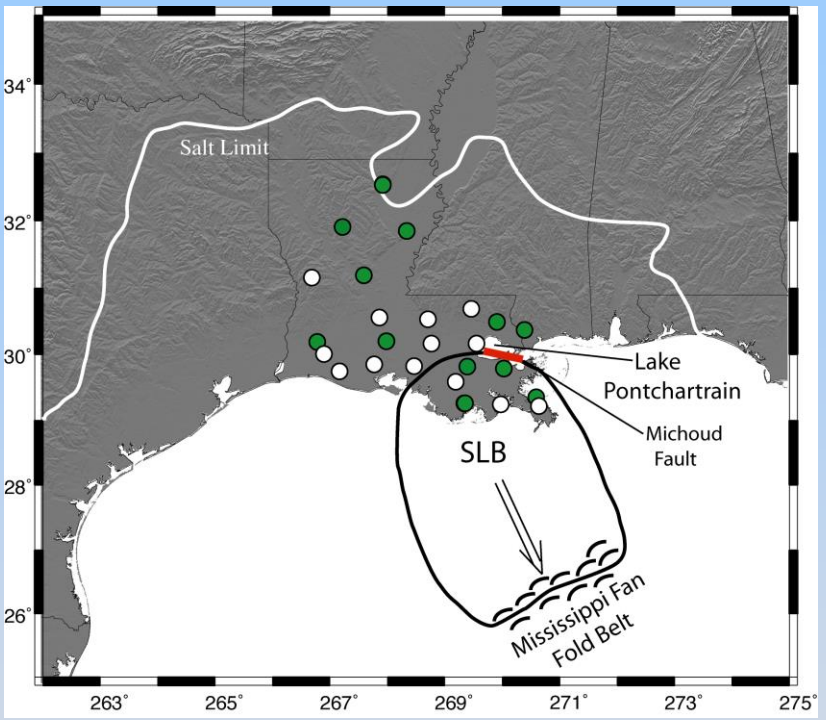
Main Cause of Low Elevation in New Orleans

- **Oxidation & sediment compaction – exponential processes**
- **Some parts of city currently lie >3 m below sea level**
- **Assume they were at or near sea level before construction of levees**

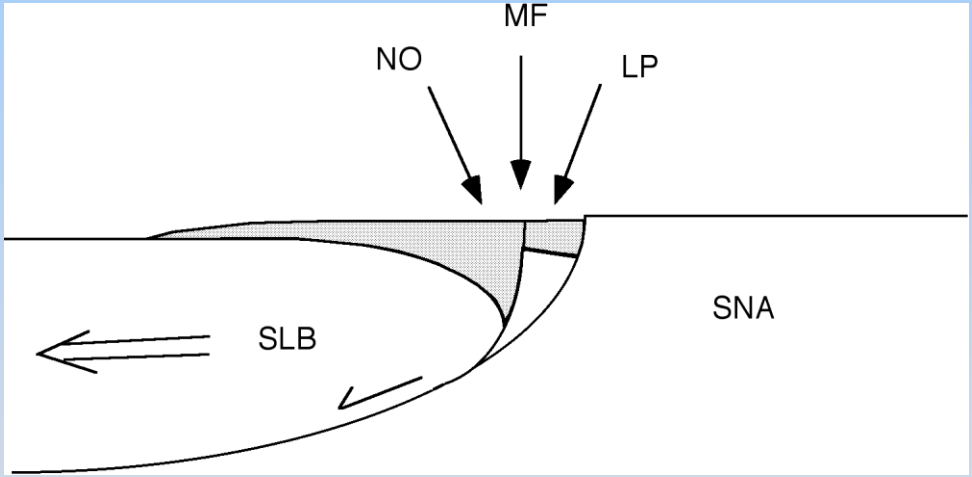
and marsh drainage (~1860 AD) began process of oxidation, sediment compaction.

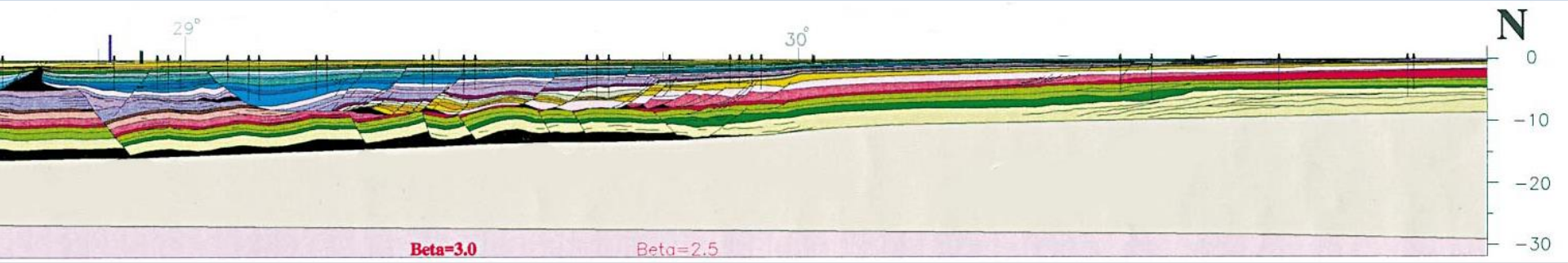


Active Tectonics May Also Play a Role



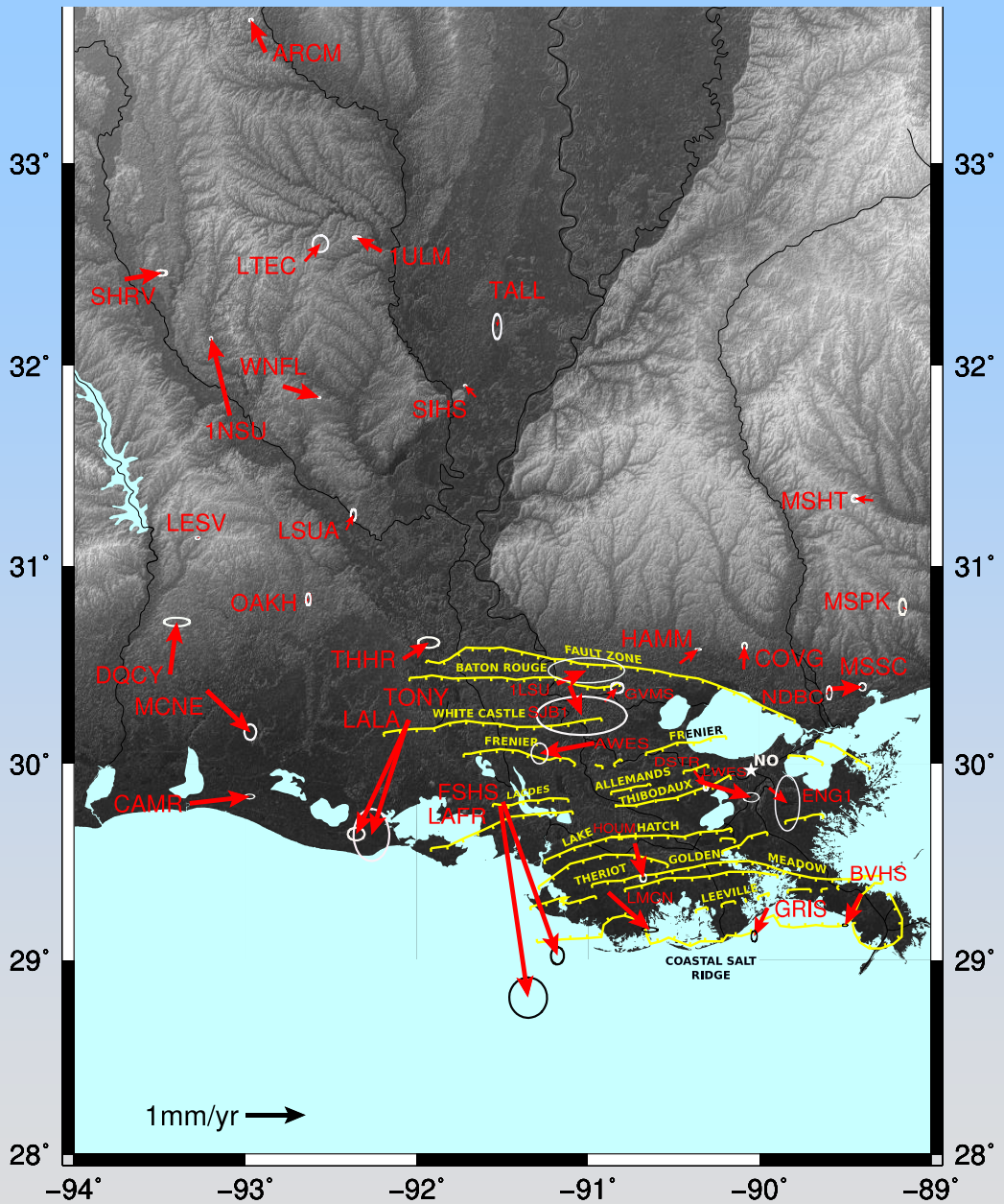
- *Mississippi Delta slides on several listric normal faults towards Gulf of Mexico
- *Weak salt layer acts as decollement
- *Mainly horizontal motion

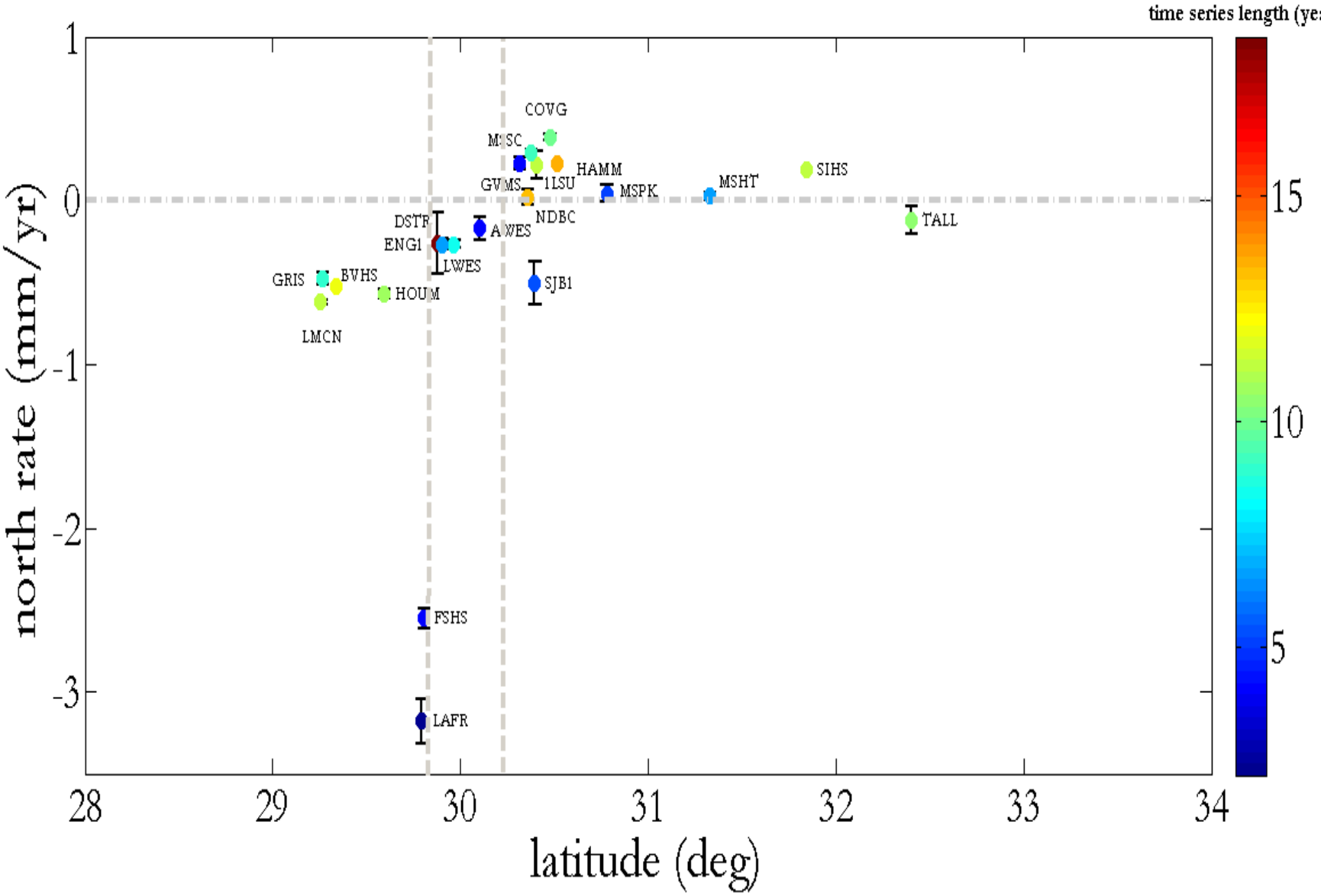


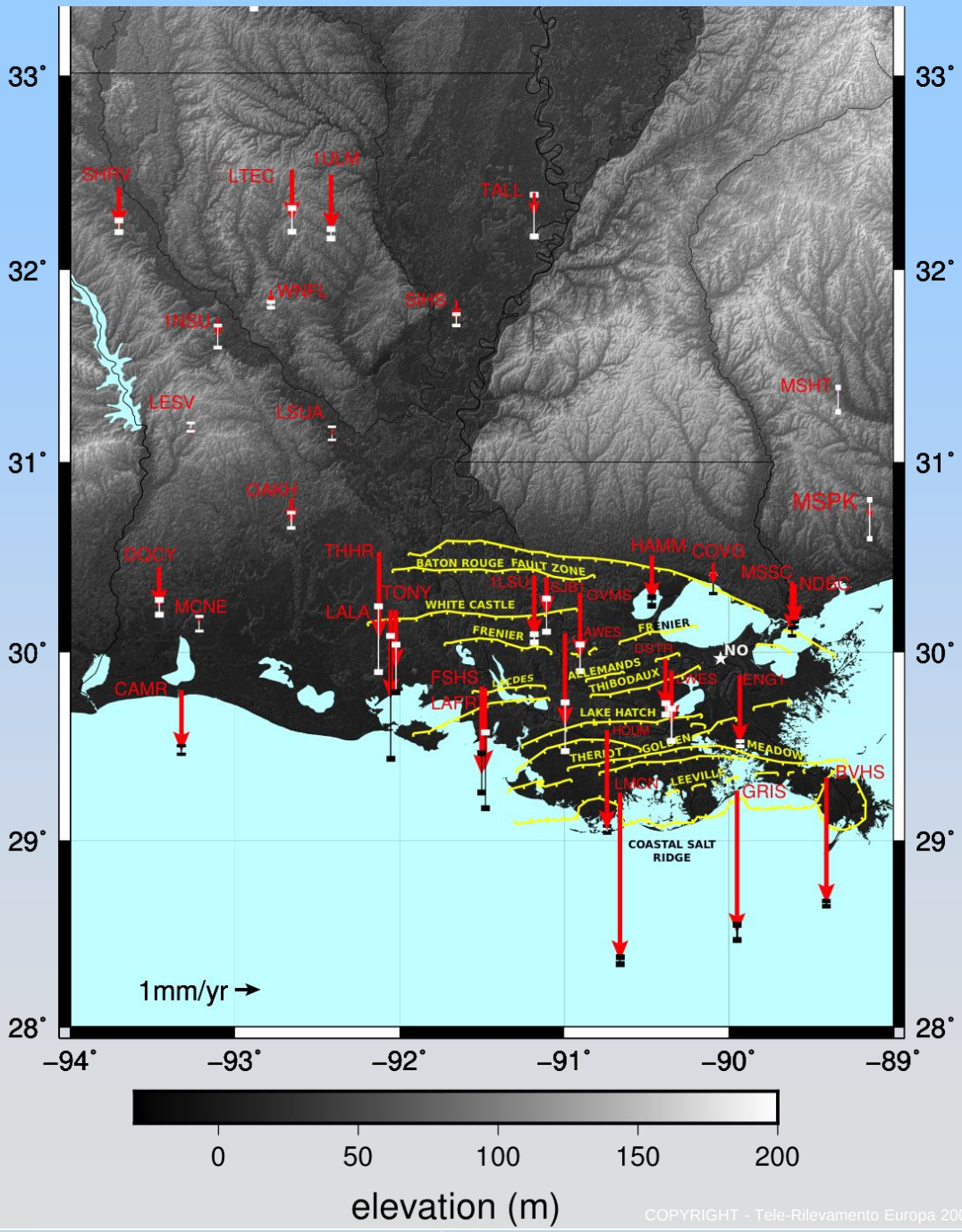


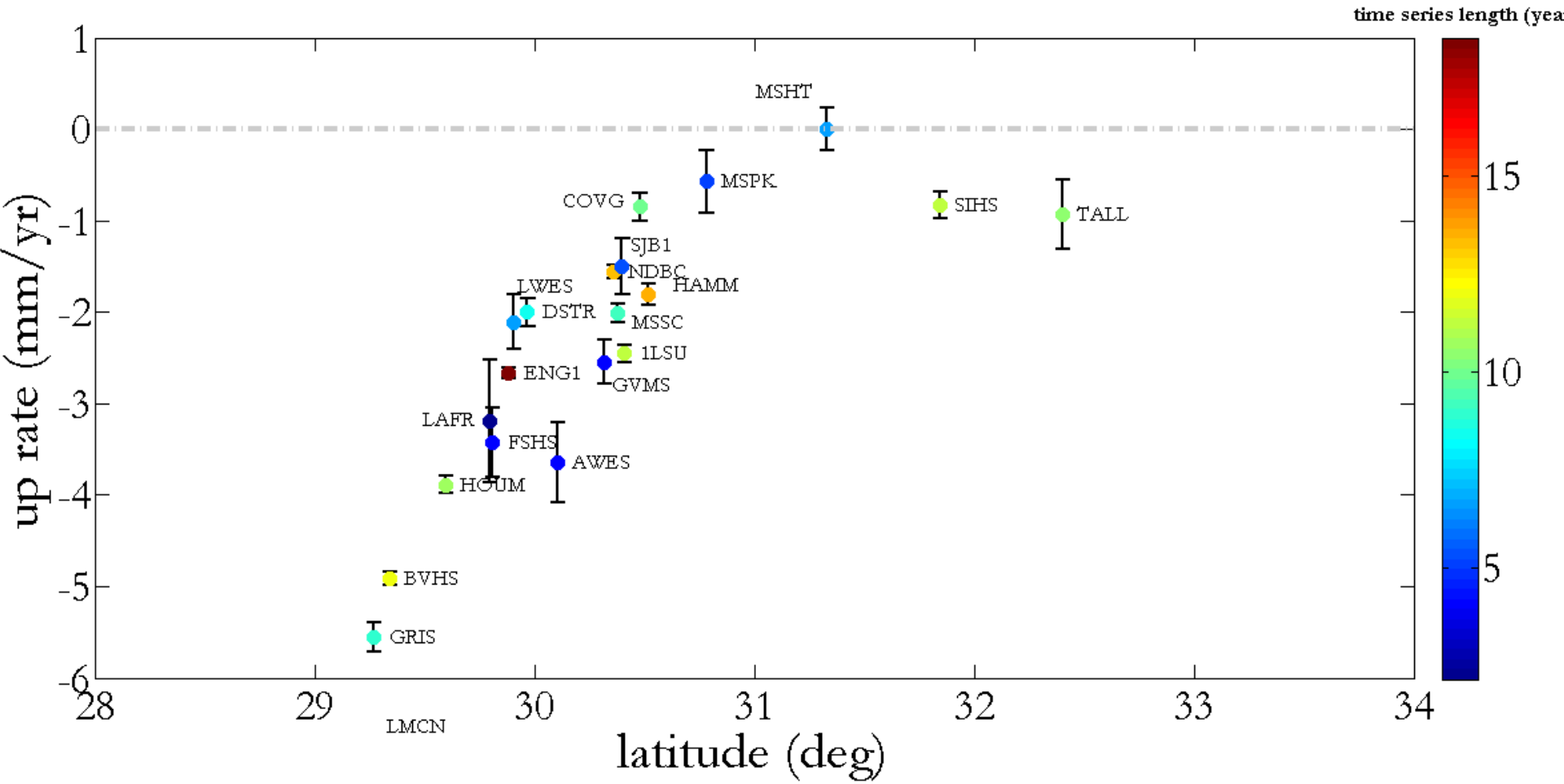
Dokka, Sella and Dixon (2006)

Geomorphic Boundary



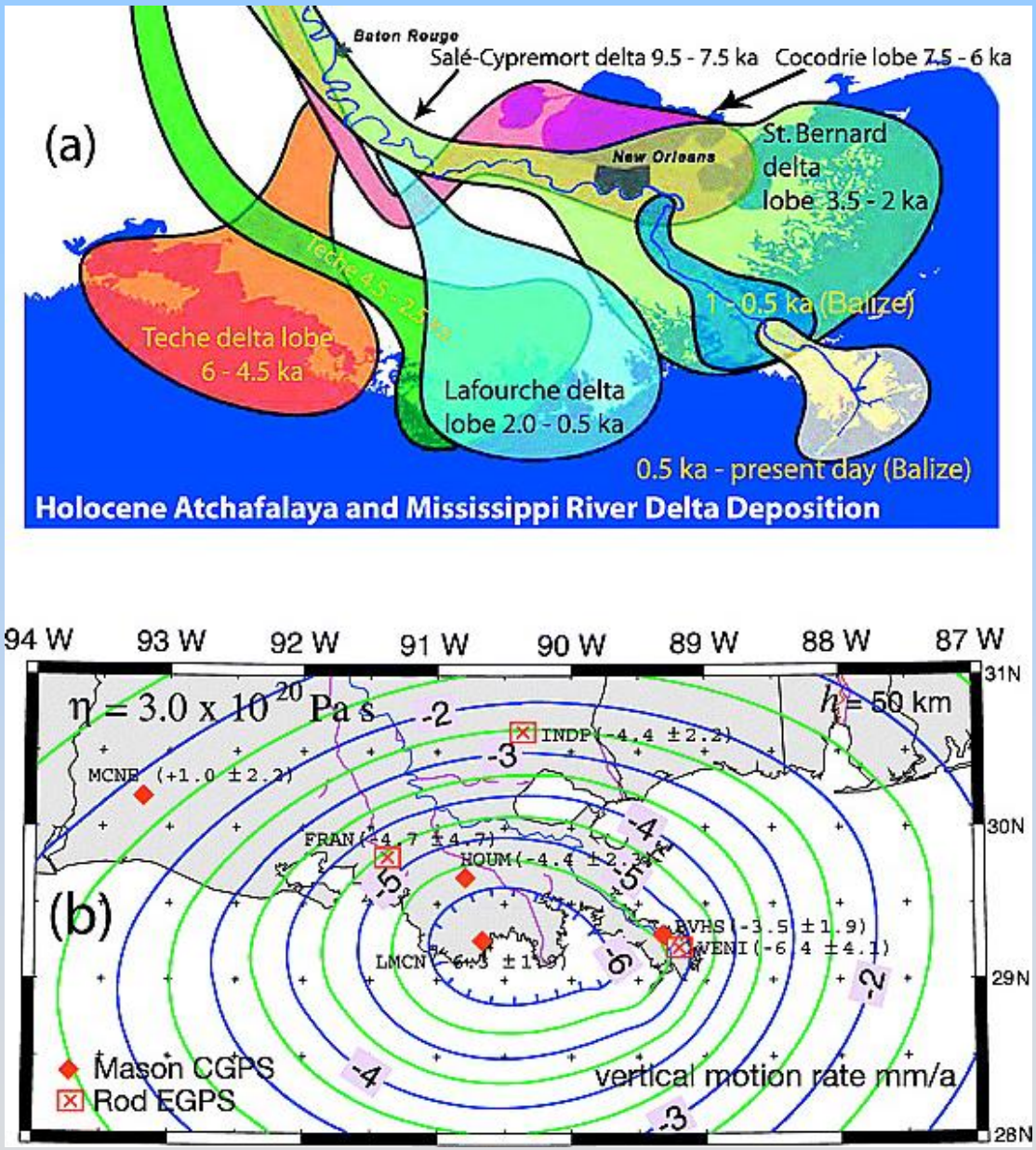






Causes of Delta Subsidence

- **Unlike New Orleans, oxidation should not be significant**
- **Compaction of Holocene sediments (1-2 mm/yr?)**
- **Mass loading of delta (Ivins et al. 2007) (3-6 mm/yr) predicts simple pattern observed**

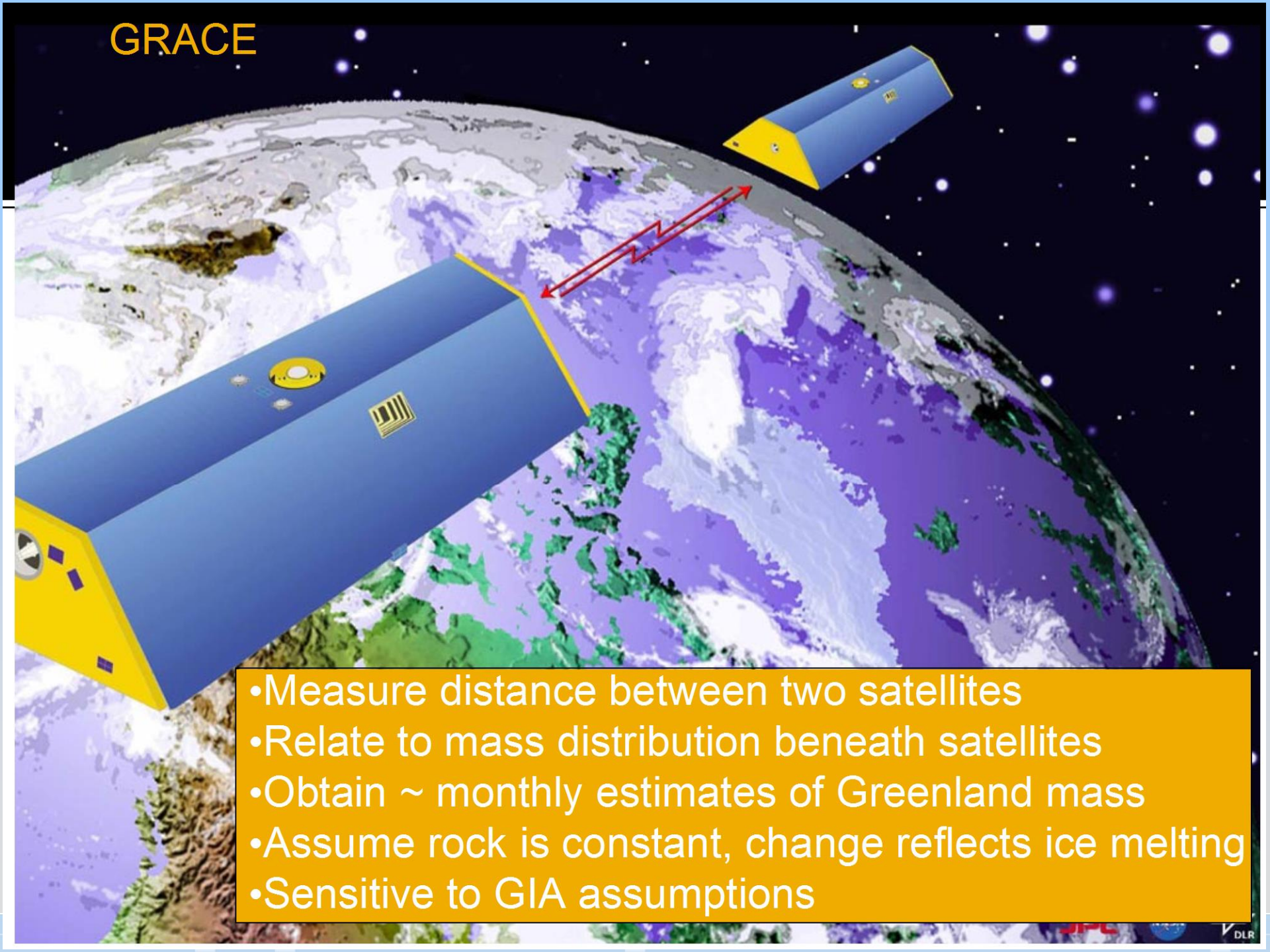


Ivins, Dokka & Blom, 2007

Causes of Horizontal Motion

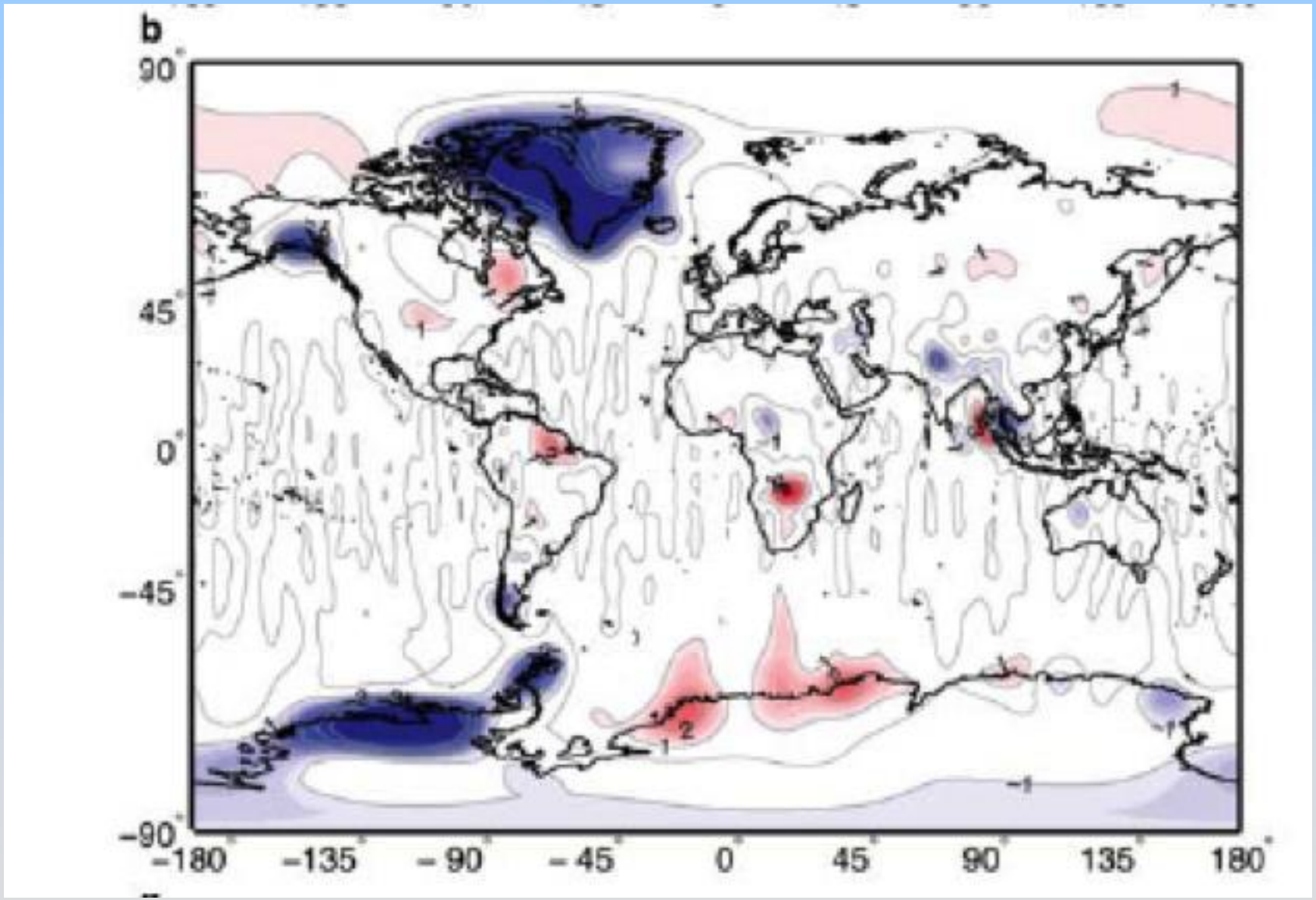
- **Southward motion at ~0.5 mm/yr reflects sliding of Miss. Delta block on deep, salt-related decollement**
- **Recent & Holocene mass loading of delta may play a role**
- **Growth normal faults are active**

GRACE



- Measure distance between two satellites
- Relate to mass distribution beneath satellites
- Obtain ~ monthly estimates of Greenland mass
- Assume rock is constant, change reflects ice melting
- Sensitive to GIA assumptions

GRACE Results, 2002-2011



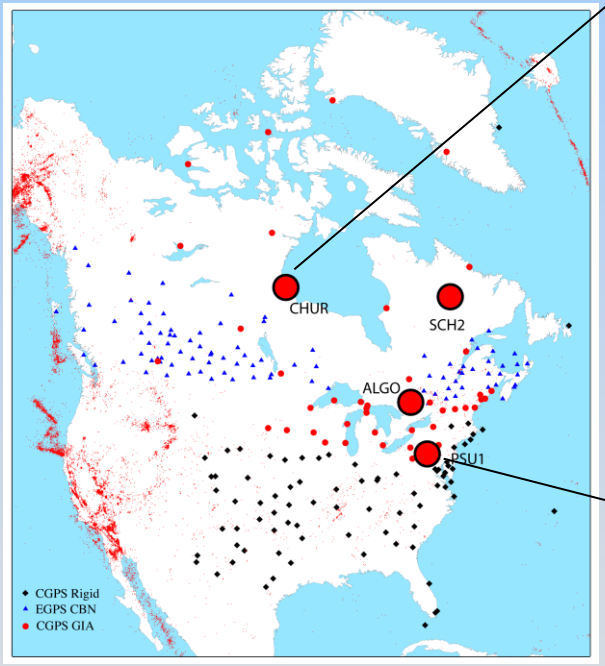
Importance of Glacial Isostatic Adjustment (GIA)

- **GIA reflects long term response of mantle to crustal unloading after Last Glacial Maximum (LGM) ~ 20,000 years ago**
- **GRACE sensitive to GIA model**
- **GIA models depend on:**
  - **Mantle viscosity structure (poorly known)**
  - **Ice melting history (very poorly known)**

What is relation of GIA to present uplift signal from anthropogenic warming?

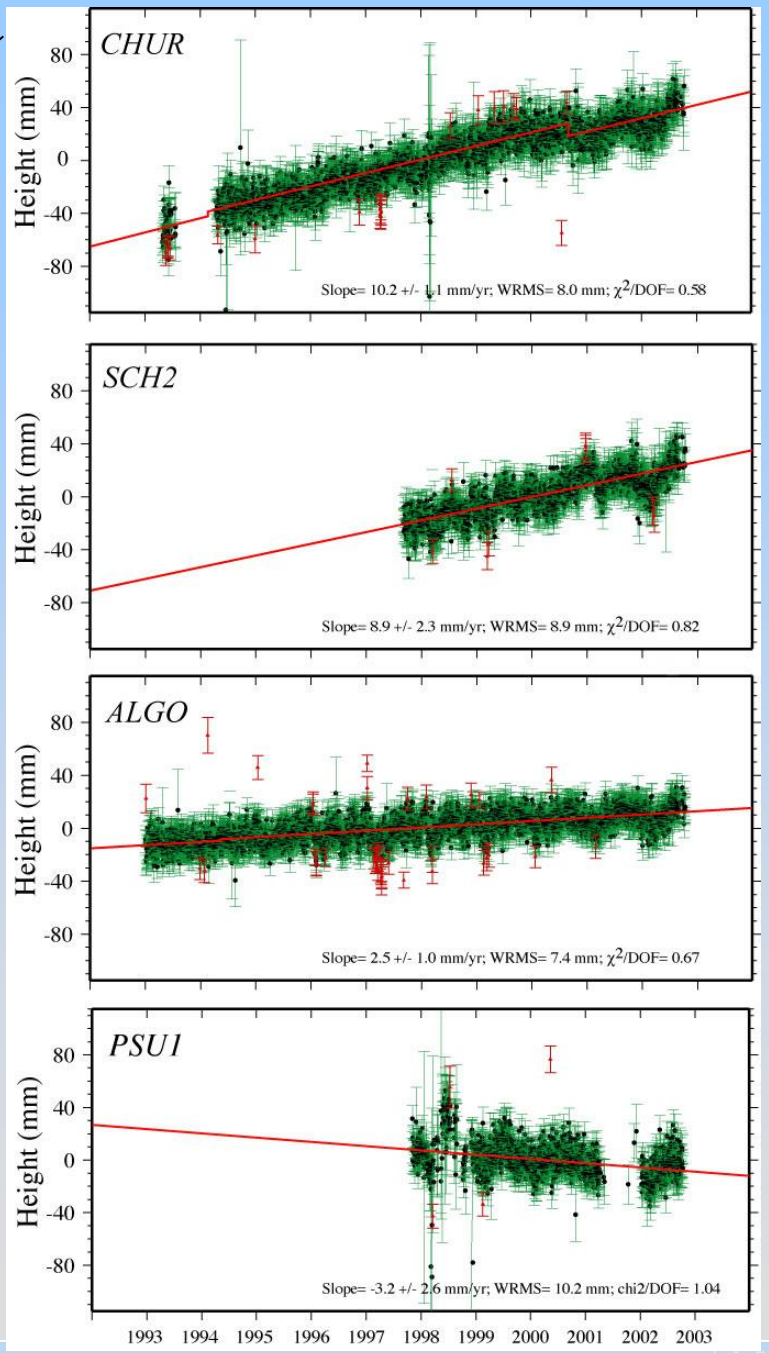
- In principle, can use isostasy to infer ice melting rate (loss of Greenland ice results in uplift)
- Problems
  - impact of past events is significant (visco-elastic response from LGM)
  - mantle viscosity limit present-day response
- GIA is both a potential tool for ice melt studies, and a noise source
- GPS can help constrain GIA, and measure present mass loss directly

- Glacial Isostatic Adjustment in North America observed with GPS
- Shows long term response to melting since LGM

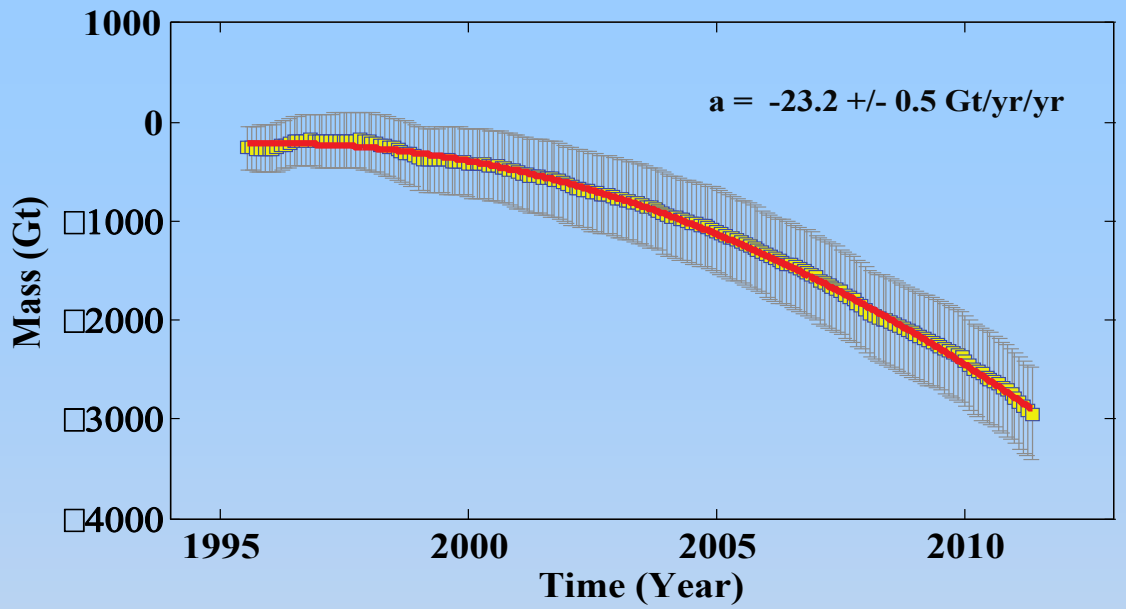


UPLIFT

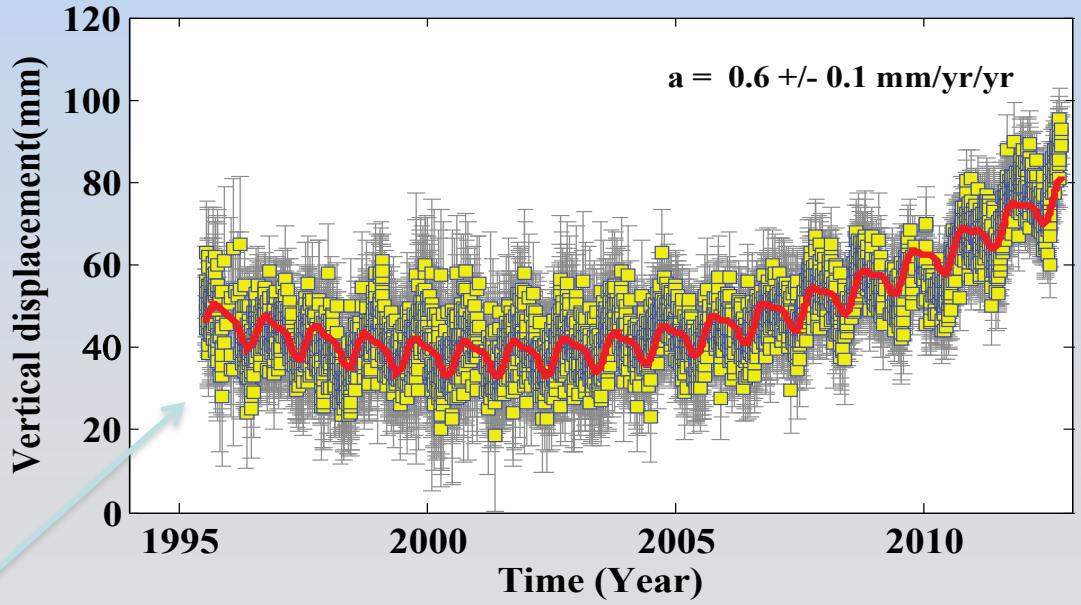
SUBSIDENCE



Cumulative changes in the mass of GrIS (Sheperd et al., 2012)

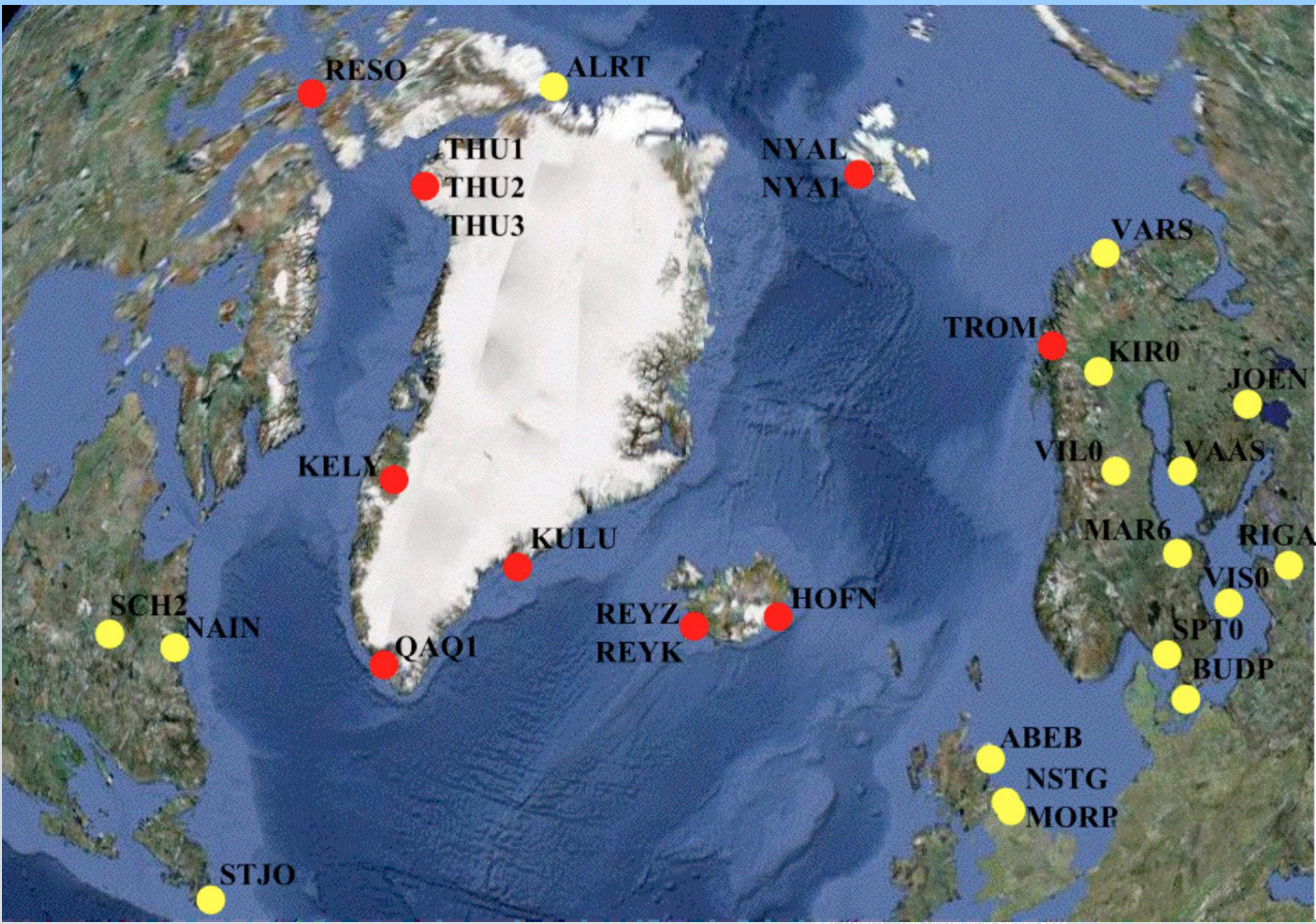


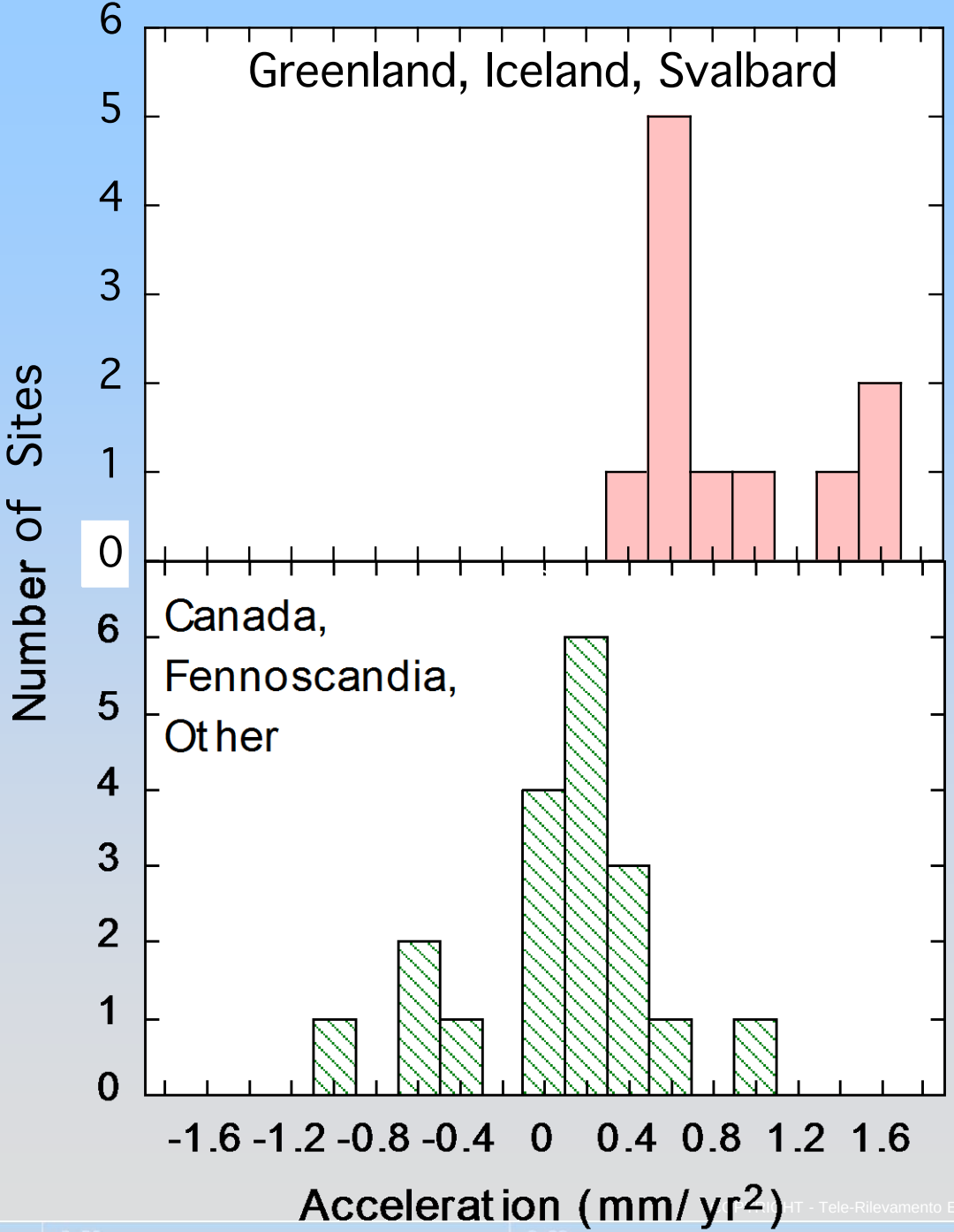
Time series of GPS vertical component position estimates for Greenland



Model (red curve):
Initial Velocity
Constant acceleration
Annual & semi-annual terms

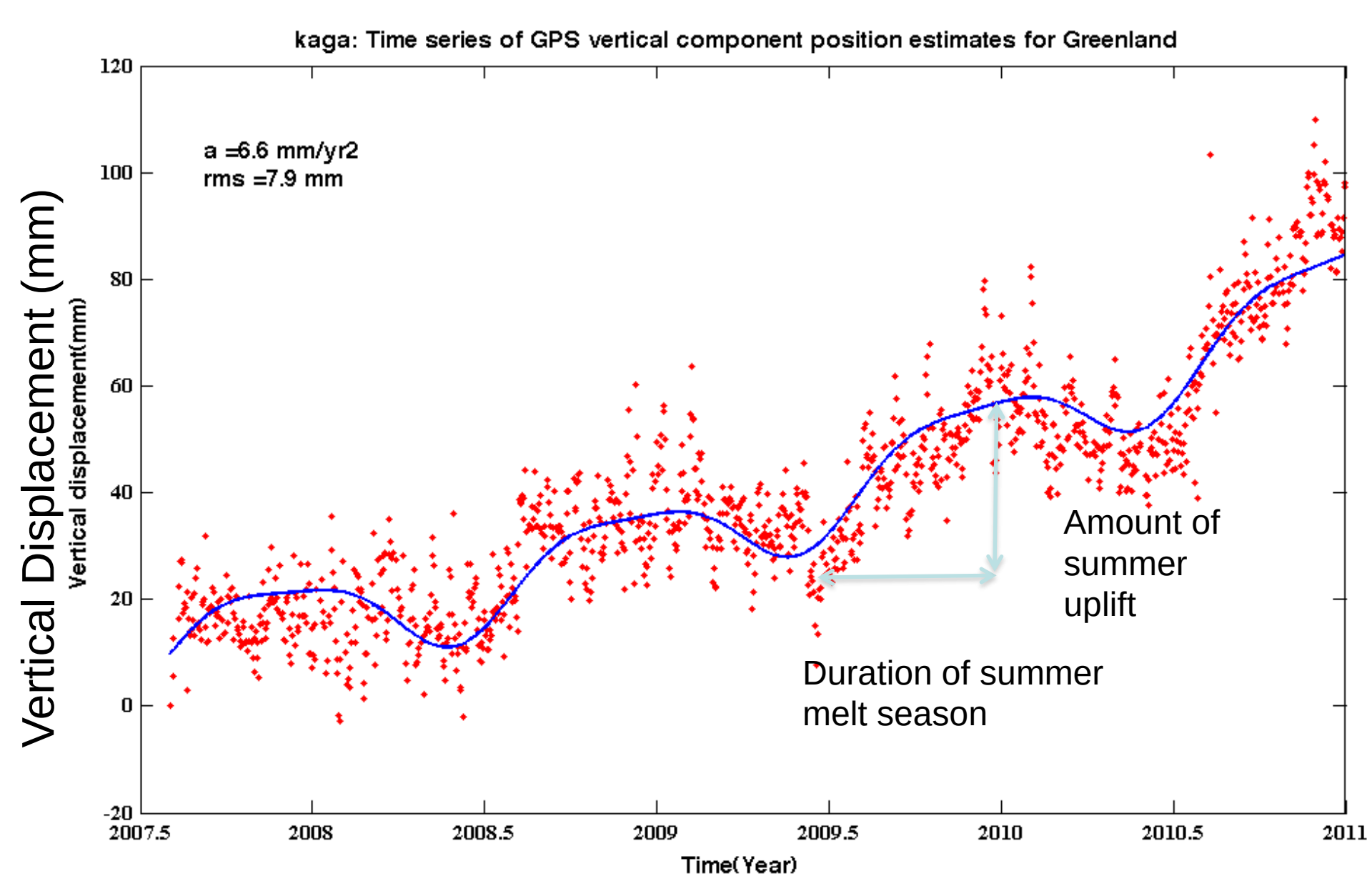
GIA


RESO
ALRT
THU1
THU2
THU3
NYAL
NYA1
VARS
TROM
KIR0
JOEN
VIL0
VAAS
KELY
KULU
MAR6
RIGA
VIS0
SCH2
NAIN
REYZ
REYK
HOFN
SPT0
QAQ1
BUDP
ABEB
NSTG
MORP
STJO



Annual Signal

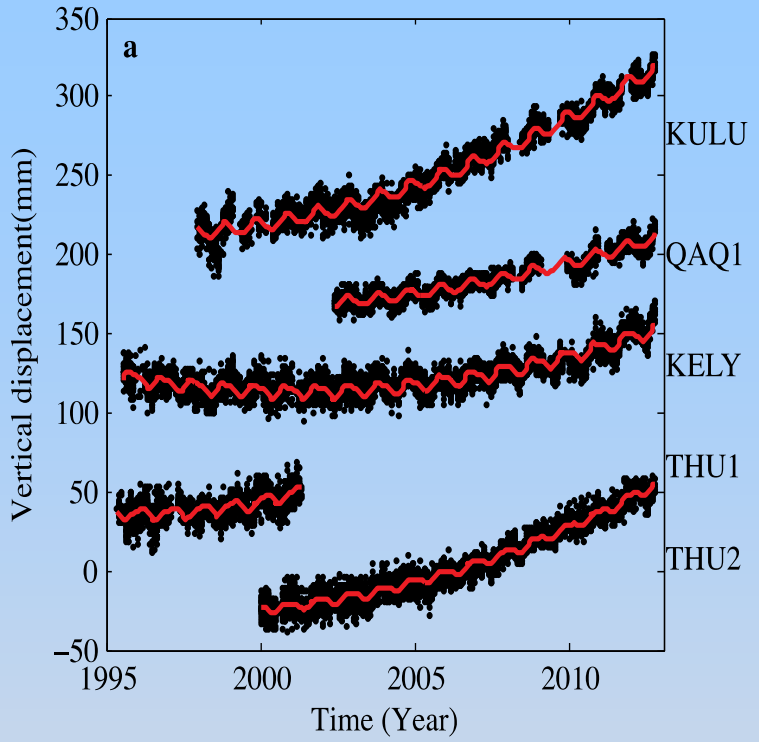
- Elastic response implies uplift sensitive to seasonal melting
- Can be used to compare annual variations, investigate details of acceleration at individual sites
- Losses occur during short summer melt season

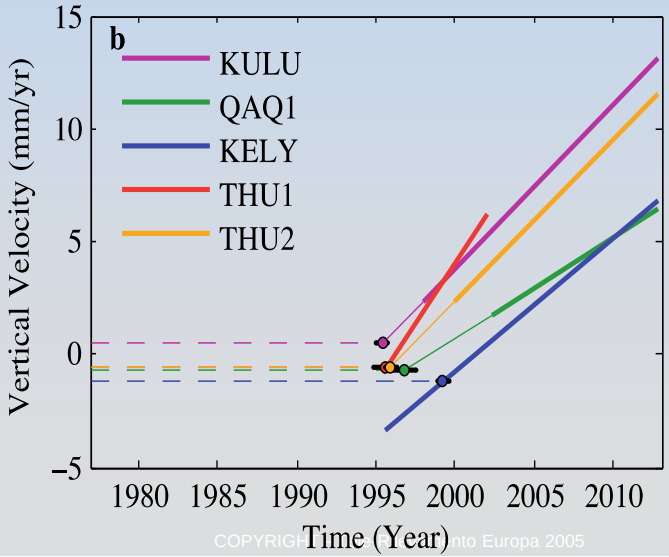


Vertical Displacement (mm)

Time (Year)

Timing of accelerated uplift from a GIA-GPS Model: mid-late 1990's, a time when many changes were happening in North Atlantic ocean circulation





Summary

- **High precision GPS can monitor geologic and anthropogenic deformation processes in Gulf coast, and details of Greenland melting**
- **1-2 mm precision in vertical component**
- **Subsidence of Miss. Delta and New Orleans levees continues, increasing future flood potential**
- **Subsidence "budget" still unclear (what are various sources?)**
- **Miss. Delta moves south at ~0.5 mm/yr, probably related to listric faults that exploit ductile salt at depth**
- **Greenland melting is accelerating. Now contributes ~ 1 mm/yr to global sea level rise budget.**